

Academy of Program / Project & Engineering Leadership

The Gravity Probe B Launch Decision



case study

THE GRAVITY PROBE B LAUNCH DECISION

In the summer of 2003, NASA Program Manager Rex Geveden was eager to ship the Gravity Probe B (GP-B) spacecraft to Vandenberg Air Force Base for integration and testing and then launch. In April the program had undergone a termination review, which in Geveden's estimation, had been a close call. Getting the spacecraft to the launch pad would remove the threat of imminent cancellation. "We have to ship this thing to Vandenberg as fast as we can possibly ship it, because nobody will 'un-ship' us," Geveden thought.

GP-B was no stranger to the threat of cancellation. By this point, it was in the home stretch of its development after earning the distinction of being NASA's longest-running project in the history of the agency. Its scientific experiment was originally conceived in 1959, just a year after NASA's founding, and it first received funding from the agency in 1964. During its nearly 40-year history, the program had faced cancellation numerous times, only to have its funding restored, often as a direct result of the personal lobbying efforts of Principal Investigator Dr. Francis Everitt of Stanford University. Even after the spacecraft had been shipped to Vandenberg, the possibility of cancellation due to a delay still loomed large for all parties involved.

Cancellation wasn't the only dark cloud on the horizon; other issues cast long shadows at NASA that year as well. The Space Shuttle *Columbia* was lost on February 1, 2003 during its return to Earth, and in the aftermath the agency endured intense scrutiny. An accident investigation took place throughout the spring and summer, culminating in the release of the Columbia Accident Investigation Board (CAIB) Final Report in late August. The report was highly critical of NASA, faulting its approach to risk management and safety as well as its organizational culture. In this heated political context, everyone working with or for NASA was keenly aware that all eyes were on the agency.

GP-B arrived at Vandenberg in July. As NASA and its contractor teams from Stanford and Lockheed Martin checked out the spacecraft and its various systems in preparation for its Flight Readiness Review, engineers reviewing the data from functional tests of the satellite's payload turned their attention to a problem with the Experimental Control Unit (ECU), a box on the spacecraft that housed a number of electronic components. (See Appendix 1, Figure 1.) The ECU, which had been slated for testing months before, created significant signal interference ("noise") in the Superconducting Quantum Interference Device (SQUID), the highly sensitive magnetic field detector that would provide measurements critical for the mission's science objectives.

An official anomaly report from Stanford University, the prime contractor for GP-B, described the findings: "...when the Experiment Control Unit (ECU) electronics box is

powered on, the SQUID signals show various degrees of DC-coupled sensitivity to the spacecraft bus voltage level.”¹

Once engineers discovered that the interference originated in the ECU, they constructed a massive fault tree to determine the possible causes of the problem. Engineers from Stanford and Lockheed Martin, the contractor that had built the box, agreed that it was a grounding issue, and that the ECU power supply was the likely culprit.

Fixing the ECU would not prove easy. The resolution of this very specific technical problem would ultimately require a significant management decision involving all the key organizations with responsibility for the development of GP-B.

A Unique Management Structure

GP-B’s management structure was unique among NASA programs and projects. In 1985 NASA had designated Stanford University as the prime contractor for the spacecraft, giving Stanford full program management responsibility. Lockheed Martin was awarded the subcontract to supply the spacecraft as well as some components of the payload, and it reported directly to Stanford, not NASA.² This arrangement, which was dubbed “The Management Experiment” by NASA Administrator James M. Beggs at the time, remained in place until 1998, when NASA decided to take a more hands-on approach as GP-B faced various technical problems. Rex Geveden, whose involvement with GP-B began in 1995 while he served as Spacecraft and Systems Manager at Marshall Space Flight Center (MSFC), assumed responsibility as the Program Manager, a position he retained even after becoming Marshall’s Deputy Center Director.

By the time the spacecraft was shipped to Vandenberg, NASA, Stanford, and Lockheed Martin had a great deal of history together on GP-B, and communication among the three organizations had become good after earlier difficulties.

A Highly Complex Spacecraft

GP-B’s bold scientific objective was to test two of the predictions of Albert Einstein’s general theory of relativity: the geodetic effect (how space and time are warped by the presence of the Earth) and frame dragging (how Earth’s rotation drags space and time around with it).³ The experiment necessary to determine this would measure if there were minute changes in the spin direction of a set of extremely precise gyroscopes placed in a polar orbit 400 miles above the Earth.

¹ “SQUID Signal Anomaly Status” PowerPoint briefing, Stanford University, October 30, 2003, p. 12.

² To learn more about The Management Experiment, see Brad Jones and Ned Calder, “Gravity Probe B: Lessons from a Management Study,” Project Management Challenge 2007 presentation. Accessed 21 April 2007 at <http://pmchallenge.gsfc.nasa.gov/docs/2007Presentations/Presentations/Calder_Jones.pdf> See also Calder and Jones, “Gravity Probe B: Testing Einstein... With a Management Experiment?” *ASK Magazine*, Issue 24. <http://appel.nasa.gov/ask/issues/24/24s_gravity.php>

³ To learn more about how the GP-B experiments sought to test general relativity, see Stanford University’s website <<http://einstein.stanford.edu/>>

The GP-B experiment required one of the most sophisticated spacecraft designs ever utilized for a NASA mission. For many less complex science missions, the spacecraft bus (i.e, the spacecraft without its instruments or electronics) serves essentially as a vehicle to transport and house the instruments. With GP-B, though, the experiments required such a degree of exactitude that the spacecraft itself played an active part in the functioning of the instruments.

**Two Distinct Effects of General Relativity:
The Geodetic Effect and Frame-Dragging**

According to the theory of general relativity, space-time can be distorted by the motion of a massive body. GP-B proposed to test two predicted effects of general relativity: the geodetic effect and frame-dragging. General relativity holds that a massive body like the Earth warps the space-time around it, creating the geodetic effect. Frame-dragging is the predicted effect that occurs when a rotating body spins on its axis, “dragging” the space-time around it.

GP-B employed the world’s most precise gyroscopes, electrostatically suspended (non-contact) and spinning in a vacuum that insulated them from the effects of any external forces. The gyro’s rotors were the most spherical objects ever produced, rotating at high speed in tight casings that they could not touch. (See Appendix 1, Figures 2a and 2b.) The maintenance of a perfectly drag-free environment required the spacecraft to use micro-thrusters to make constant minute adjustments in its position in order to keep the gyros perfectly in place.

A critical piece of hardware was a dewar, a nine-foot tall Thermos bottle that formed the main structure of the space vehicle. (See Appendix 1, Figure 3.) The dewar was filled with liquid helium cooled to a temperature of almost absolute zero, transforming the helium into a “superfluid” state so it could serve as a completely uniform thermal conductor. Filling and cooling the dewar to the proper temperature was a process that took several weeks; once cooled, its maintenance at that temperature was no simple task.

Given the complexity of the dewar and the continuous calibrations of the spacecraft’s position required to sustain the drag-free environment, it is not much of an exaggeration to say that the entire spacecraft *was* the instrument. There was zero room for technical performance error.

Within this highly integrated structure, the ECU housed multiple electronic instruments and gauges. Its most critical role was to control the Gas Management Assembly (GMA) that would spin up each of the gyroscopes by blowing a stream of 99.99% pure helium gas over each gyroscope’s rotor. In addition to housing the GMA, the ECU’s instruments also monitored the dewar, acting as a fuel gauge.

Fix or Fly?

Because the ECU was already on the spacecraft, which was far along in its integration process, fixing it would be no easy matter. By the time the analysis of the ECU problem was completed in October 2003, the dewar had been filled, cooled, and sealed. The spacecraft's four solar arrays were being installed. Momentum was building toward the launch, which was scheduled for December, 6, 2003.

The leader of the Stanford team, Program Manager Gaylord Green, was confident that the ECU did not pose a risk to the mission because of the extensive test program he had implemented. From his point of view, the ECU only had to work long enough to spin the gyros up to speed; it could then be turned off so the noise in the signal did not interfere with the experiment data. "I was fairly comfortable that the ECU would work on orbit for the length of time (necessary)," he said. "If we shut the ECU off at that point, what we lost was the dewar monitoring and some of our instrumentation on our cryogenics. I was confident that it would spin up the gyros, I was confident that we could succeed through the mission, and so I pushed hard that we should go ahead and fly."

Bill Bencze, Stanford's electronics manager at the time, saw the problem differently than Green did. "My chief worry was ECU reliability; the system had to function during the checkout phase of the mission or the mission would fail," he said. "Experience with other DC-to-DC converters (power supplies) of this type in other boxes showed them to be quite fragile when operated improperly."

Lockheed Martin, which had built the ECU, had its own Mission Assurance team at Vandenberg working the problem. Bill Reeve, Lockheed's Program Manager for GP-B, focused on the reliability question. "You couldn't initialize the experiment without the ECU working. It only needed to work for a few months, but it did need to work. If the ECU failed initially when it got up on orbit, we wouldn't have been able to initialize the science experiment and the whole mission would have been a failure."

The prospect of de-integrating GP-B, pulling the ECU, and then reintegrating the spacecraft carried the significant risk that something would be damaged in the process; none of the parties working on it underestimated its complexity. Every day at the launch pad added risk to the overall mission. There was also pressure in terms of human resources. The Boeing team at Vandenberg in charge of the Delta launch vehicle for GP-B was scheduled to move on soon to another mission.

Decision Time

The ultimate authority for the decision rested with NASA, which had final responsibility for the mission. Ed Ingraham, a member of the NASA team at Vandenberg, requested that Stanford compile a list of everything that would need to be re-handled if the ECU was taken off the spacecraft.

In order to remove and repair the ECU, the following items would have to be removed and re-installed: all four solar arrays, which were extremely touch-sensitive; numerous thermal blankets; and the Forward Equipment Enclosure (FEE), which housed a majority of the science electronics boxes. The dewar would also have to be serviced to maintain its superfluid temperature and pressure. The original installments took three months, and the solar arrays would become particularly vulnerable by being handled twice. There was also the issue of “unknown unknowns,” such as earthquakes.⁴ “Some engineers were saying if we take it off, there’s more risk than if we leave it on,” said Brad Jones, the Stanford Launch Team Lead at Vandenberg.

“You run a risk anytime you take a box off, peer into it, and reintegrate it on the launch pad,” said Gaylord Green. “You always run the risk of something else going wrong. That decision is not without risk on both sides.”

At Marshall Space Flight Center, Rex Geveden, who was both Deputy Center Director and GP-B Program Manager, chaired a Configuration Control Board meeting for GP-B. He and Marshall Center Director Dave King solicited opinions from the Center’s engineering and safety & mission assurance organizations about how to handle the ECU. Buddy Randolph, the GP-B Chief Engineer, and Jeff Kolodziejczak, NASA’s GP-B Project Scientist, both advocated in favor of proceeding to launch without pulling the ECU.

No decision was made at the Configuration Control Board meeting. Afterward Geveden met with some members of the Marshall GP-B team in his office, including Ingraham, who had flown out from Vandenberg and was on his way back. Ingraham mentioned the concerns of Bill Reeve from Lockheed. Geveden had worked with Reeve in the past and respected his expertise. He decided to speak privately with Reeve. He also spoke privately with Gaylord Green.

As the integration process continued at the launch pad, tensions neared a boil. The Payload Attach Fitting (PAF), which joined the spacecraft with the launch vehicle, had been mated. The next step was the installation of the explosive bolts that would allow the spacecraft to separate from the launch vehicle during ascent. This was the point of no return, after which it would be impossible to pull the ECU. It was time for a decision that only the program manager could make it.

(End Part I)

⁴ This was not a trivial concern: California experienced a notable earthquake in the Vandenberg area about four weeks after a decision was made about the ECU.

Appendix 1. Illustrations



Figure 1. The Experimental Control Unit (ECU). (Source: Rex Geveden, “Forum of Master Project Managers” presentation, August 2004.)



Figure 2a. The GP-B gyroscope rotors are listed in the Guinness Book of World Records as the most spherical objects ever produced.
(Source: [NASA](#))

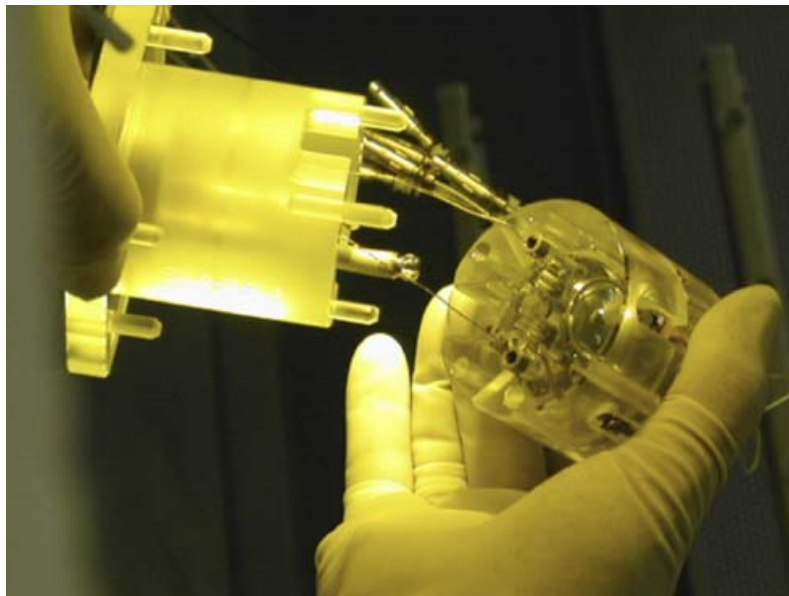


Figure 2b. A member of the GP-B team inspects one of the gyroscopes.
(Source: [NASA](#))



Figure 3. The Gravity Probe-B dewar was shaped like a giant Thermos bottle.
(Source: [NASA](#))

Appendix 2. Gravity Probe B Launch Decision – Conclusion

Against the advice of his GP-B Chief Engineer at Marshall and his prime contractor's Program Manager at Stanford, Geveden decided to scrub the launch and pull the ECU. Early estimates were that the total cost of the decision would be \$20 million.

Once the cover came off the ECU, the teams from Stanford and Lockheed found more problems than they expected. "When we pulled the box...we actually found three other problems in the design," said Bill Bencze of Stanford. "Once you popped open the box and found these other issues that weren't apparent from the schematics, you were able to fix those (as well)."

The Lockheed team that examined the box found that the power supply cases were not grounded, and that due to a design flaw the box employed the wrong filter pin connectors for the box's switching converters, which handled very high power density at very fast switching times.

At that point, Bill Reeve of Lockheed had very little confidence in the ECU. "I asked for an independent audit of all the circuits in the box, and I brought in electronics experts from around the country to come and have a review of every single circuit in the box. And I think they found 20-some issues—I don't remember the (exact) number of issues," he said. "We went through every single one, to determine whether or not they need to be repaired, need to be fixed, to make sure that all the proper analyses were performed to make sure the box was healthy."

The box was repaired and returned to the spacecraft. The total cost of the stand-down was close to \$11 million. The teams from Stanford and Lockheed reintegrated the spacecraft and prepared it for launch. Five and a half months after the decision to scrub the launch, Gravity Probe B lifted off successfully from Vandenberg on April 20, 2004.

Appendix 3. Teaching Notes

This case study has been designed to be delivered in two parts. Participants should be given pp. 1-6 and Appendix 1 (pp. 7-9) to read prior to in-class discussion, preferably as a homework assignment or “read-ahead” that allows ample time for analysis and reflection.

The facilitator should then lead a guided discussion, focusing on the class’s interpretation of the problem:

- What pressures affected the various stakeholders in the case?
- How did the different stakeholders characterize the ECU anomaly in risk management terms?
- What organizational or managerial factors may have complicated the decision-making process for the Program Manager?

Participants should be encouraged to draw analogies to their own experience and develop as many options as possible.

The facilitator should then distribute Appendix 2, “Gravity Probe B Launch Decision—Conclusion” and allow the participants 5 minutes to read what happened with the case. The concluding discussion should encourage participants to consider:

- Why do you think the Program Manager reached the decision that he did?
- How did the Program Manager manage risk?
 - What risks did he choose to mitigate?
 - What risks accompanied his decision?